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An Efficient Methodology for Reservoir Release Optimization using Plant Propagation Algorithm

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Abstract

Water from the Reservoir is used for multiple purposes such as irrigation, hydropower generation, supply of drinking water, industrial purposes, management of fisheries, and flood control. Reservoir water should be utilized effectively in order to use water in an optimal fashion. Reservoir optimization is a continuous optimization problem which is also a NP-hard in nature. In this paper, nature inspired Plant Propagation Algorithm (PPA) is applied to perform Implicit Stochastic Optimization (ISO) for optimal release of water from the reservoir. PPA emulates the way in which the strawberry plant propagates. The search process of the plant is used to identify different optimal release patterns, the best maximal release with respect to varying storage and demand and also releasing water during dry months when there was no inflow. The study area chosen for this research work was Thirumurthi Reservoir located in Tiruppur district of Tamilnadu in India. The main purpose of this research work is to release water optimally in the normal months, so that water can be saved and can be utilized in the dry months. The results obtained in this research work were promising and shows that PPA offers a good scope for optimal release with available water in the reservoir, also by satisfying demand to a greater extent. Release patterns for varying inflow, storage and demand ranges were generated in this work using 5 years (2009 to 2013) of real time data collected from Thirumurthi reservoir, which could serve as a guideline for optimal reservoir release.

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Keywords: Reservoir Release Optimization; Plant Propagation Algorithm; Regression based ISO model; Release patterns in normal and dry months.

1. Introduction

Reservoir Optimization is a continuous optimization problem where the flow of one month has influence on the flow of next subsequent month and so on. In a single-reservoir operation, the operating rule is found to provide reservoir system operators with long-term reservoir operating policies. In deciding how to step from one iterate to the next, the algorithm makes use of knowledge gained at previous iterates, and information about the model at the current iterate, possibly including information about its sensitivity to perturbations in the variables[2].

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In this research, Plant Propagation Algorithm was proposed for Implicit Stochastic Optimization (ISO) to optimize the reservoir releases. Regression based ISO model was used for optimal release of water for different inflow and demand ranges. The proposed methods were tested with real-time reservoir data collected from Tamilnadu Public Works department of Thirumurthi reservoir located in Tiruppur district of Tamilnadu. The optimal release results obtained were also compared with actual outflow of the reservoir. The experimented results have shown the suitability and effectiveness of plant propagation algorithm for reservoir optimization.

2. Study Area

The test data for this research work were collected from Tamilnadu Public Works Department (PWD) of Thirumurthi reservoir for 5 years (2009 to 2013). Thirumurthi reservoir is situated in Tiruppur district of Tamilnadu state in India.

3. Objective of the Research

The main aim of this research work was to optimize the reservoir releases during drought conditions, based on the storage level, inflow and demand. The initial storages, inflows and optimal releases were used to estimate the operating rules.

The objectives of this research work are,

- To generate a Standard Operating policy for optimal reservoir releases.
- To propose Strawberry algorithm for Implicit Stochastic Optimization of reservoirs.
- To test the effectiveness of the proposed technique with the real time case study, Thirumurthi reservoir.

4. Reservoir Optimization using Plant Propagation Algorithm

Reservoir Operations considers the factors that authorities the reservoir's capability to stock up and release of the water. Optimization of Reservoir Operation is one of the major focuses of water resource development. There are different conflicting objectives for different types of stakeholders such as hydropower generation, allocation of water for irrigation, supply of drinking water to people, water allocation for industrial purposes etc., Therefore, it is necessary to optimize the reservoir operation in order to determine balanced solutions between the conflicting objectives[3]. In this research work, Reservoir Release optimization, a continuous optimization problem is solved using Plant propagation algorithm..

Release and stock up of water at each time period were related to inflow and spill of water which can be derived using continuity equation for the system as in equation (1),

$$\mathbf{St(n)=St(n-1)+In(n)-Ev(n)-Re(n)-Sp(n);}\ \forall \boldsymbol{n} \tag{1}$$

Where St(n) is the storage level of reservoir at end of the month n (when n=1, St(n-1) is equal to S0, the initial storage level); the storage level for the consecutive months St(n-1) will be the previous month's end of the day's storage level. In(n) and Ev(n) are the inflow of water and evaporation rate during month n[5]. Sp(n) is the spill water that might ultimately fall from the reservoir as a result of overflow, during the month n. It is also important to take care of the factor that reservoir capacity should not be less than the dead storage[4].

The physical limitations considered were given in equations (2), (3) and (4):

$$\mathbf{0 \le Re(n) \le} \boldsymbol{De(n)};\ \forall \boldsymbol{n} \tag{2}$$

$$\mathbf{S_{dead} \le St(n) \le S_{max};}\ \forall \boldsymbol{n} \tag{3}$$

$$\mathbf{Sp(n) \geq 0;\ \forall n} \tag{4}$$

where S_{dead} is the dead storage level and S_{max} is maximum storage ability of the reservoir.

The Standard Operating Policy (SOP) was used for calculating the water to be released which gives reliability to the reservoir system.

$$\begin{aligned} \mathbf{Re_n} &= \mathbf{De_n \ \ if\ \ St_{n-1} + Q_n - Ev_n \geq De_n} \\ &= \mathbf{St_{n-1} + Q_n - Ev_n\ otherwise} \end{aligned} \tag{5}$$

The excess water drained out (spill overflow) during the period n is given in the equation (6)

$$\begin{aligned} \mathbf{Sp_n} &= \mathbf{(St_{n-1} + Q_n - Ev_n - De_n) - K\ (total\ capacity)\ if\ +ve} \\ &= \mathbf{0\ otherwise\ (if\ -ve)} \end{aligned} \tag{6}$$

Where $Sp_n(n)$ is the spill overflow of the month, St_{n-1} is the previous month's storage, Qn is the inflow level of the month, Ev_n is the evaporation level, De_n is the Demand that is water required to be released , K is the total capacity of the reservoir[9].

In accordance with Standard Operating Policy (SOP), if the existing water (storage, Sn-1+ inflow level, Qn – evaporation range, Ev_n) at a particular time period is less than the demand De_n, then all the existing water was released. If the existing water is greater than the demand then the release of water is equivalent to the demand. The surplus water overflowing even after release of water is called as spill.

The surplus of reservoir was calculated as, if the existing water after water release ie., ((St_{n-1} + Qn – Ev_n – Dn) – K) at a particular time period gives a positive result, the surplus water that is overflowing is sent out as spill[8]. If the existing water even after water release is negative, there will be no spill.

4.1 Regression-based Implicit Stochastic Optimization model

Regression-based Implicit Stochastic Optimization model originally group the optimal operating data found using continuity equation as in equation (4) of the ISO method month by month (from January to December). The method was used for the months which have 70% of the inflow, which is said to be normal months. This is achieved by training the release of water on reservoir storage level at the beginning of the month and inflow for the month[1]. The regression analysis was applied to fit the following nonlinear equation to the real time data as in equation (7):

$$\mathbf{R(t) = D(t)} \left[\frac{\sqrt{S(t-1)^2 + I(t)^2} - \sqrt{S_{dead}^2 + I_{min}^2}}{\sqrt{S_{max}^2 + I_{max}^2} - \sqrt{S_{dead}^2 + I_{min}^2}}\right]^{\mathbf{m}} \tag{7}$$

Where, I_{min} and I_{max} are the minimum and maximum inflow values respectively. The above equation is termed such that the minimum storage of a particular month (S(t-1) = Sdead) combined with minimum inflow of the month (I(t) = I_{min}) provides no releases i.e., (R(t) = 0) and maximum storage water of particular month (S(t-1) = S_{max}) combined with maximum inflow of the month (I(t) = I_{max}) provides maximum releases (R(t) = D(t)). The regression analysis was made between historic and synthetic data. Rule curves are the representation to show the strategy for long term reservoir operation[7]. Rule curves were generated for storage, inflow demand and release.

4.2 Regression-based ISO model of dry months

Almost all the reservoirs in India were dry in the dry season. In Dry months the inflow values will be equal to zero or nearer to zero. A month is said to be a dry month, when at least 70% of its inflow ranges were equivalent to zero. For those dry months, the releases Re(t) of the reservoir were trained only based on the storage S(t). The regression equation for the dry months is:

$$\mathbf{Re(t) = D(t)} \left[\frac{S(t-1) - S_{dead}}{S_{max} - S_{dead}}\right]^{m} \tag{8}$$

The aim is to find the parameter value, 'm' that best fits the above equation to the data from optimization model for each and every month. The inflow values were zero in synthetic inflow model also. So the regression based ISO was also applied to dry months of synthetic inflow model.

4.3 Plant Propagation (Starwberry) Algorithm

The Plant Propagation Algorithm (PPA) is a new metaheuristic algorithm, which has recently been introduced. PPA is nature inspired and it emulates the way plants, in particular the strawberry plant, propagates. If the plant is in a good spot of the ground, with good amount of water, nutrients, and light, it will propagate through soil and send many short runners that will give new strawberry plants and occupy the neighborhood as best they can[6]. It can be explained as,

A plant p_i is in the position X_i in dimension n. This means the value of X_i is given as,

$X_i = \{x_{i,j}$ for $j = 1, \ldots, n\}$. Let us assume the number of strawberry plants to be used initially as NP. The parameters used in the PPA are, the population size is expressed as NP which is the number of strawberry plants, the maximum number of generations were represented as g_{max}, and the maximum number of possible runners were represented as n_{max} per plant. In the initial version of PPA, g_{max} is kept as the stopping criterion.

Pseudocode of Plant Propagation Algorithm

Procedure Strawberry Algorithm ( )
Begin
1. *Initialization: Generate a Population P = {Xi, i=1,2,………NP};*
2. *g←1;*
3. *For g = 1:gmax do*
   (i) Compute the value of Ni = f(Xi ∈ P);
   (ii) Sort P in the ascending order of N (for minimization); (or)
   Sort P in the descending order of N (for maximization);
   (iii) Create a new population ∅;
4. *For each Xi, i=1,2,…………,NP do*
   (i) ∝i ← set of runners where both the size of the set and the distance for each runner (individually) are proportional to Ni, the normalized objective value.
   (ii) ∅ ← ∅ ∪ ∝i (appending to population);
5. *End of for*
6. *P ← ∅ { the new population};*
7. *End of for*
8. *Return P, the Population size of the Solutions*

End Procedure

4.4 Plant Propagation Algorithm for Reservoir Optimization

The algorithm finds the way of using the objective function rate at different position of the plant X_i, i = 1, . . . ,NP, in a normalized form N_i, to rank them. Let Ni ∈ (0,1) be the normalized objective function value for Xi. The number of plant runners $n_{\propto}^{i}$ were calculated according to (9) below, has length dx^{i}calculated using the normalized form of the objective value at X_i, each giving a $dx^i \in (-1,1)$ n , as calculated with (10) below. After each and every individual (plant) in the whole population have sent their allocated runners, new plants (offspring) were examined and the entire increased population is sorted. The number of runners assigned to a given plant is directly proportional to its fitness function as in equation (9)

$$\boldsymbol{n^i_\propto} = \lceil \mathbf{nmax\ Ni} \ \propto \rceil, \quad \propto \in (\mathbf{0}, \mathbf{1}) \tag{9}$$

Every solution of normalized form of objective value at X_i, generates at least one runner and the length of each runner is inversely proportional to its growth as in equation (10) below:

$$\boldsymbol{dx^i_j} = \mathbf{2(1} - \boldsymbol{N_i}\mathbf{)}\ (\boldsymbol{\alpha} - \mathbf{0.5}), \quad \mathbf{for}\ \boldsymbol{j} = \mathbf{1}, \ldots, \boldsymbol{n} \tag{10}$$

where *n* is the problem dimension. Having calculated dx^i , which indicates the extent to which the runner will reach to find good spot, the search equation that finds the next neighbourhood to explore is given by equation (11),

$$\mathbf{y_{i,j} = x_{i,j} + (b_j - a_j)}\ \boldsymbol{dx^i_j}, \quad \mathbf{for}\ \boldsymbol{j} = \mathbf{1}, \ldots, \boldsymbol{n} \tag{11}$$

If the limits of the search domain are violated, the point is adjusted to be within the domain $[a_j, b_j]$, where a_j and b_j are lower and upper limits delimiting the search space for the j^{th} coordinate.

The Strawberry Algorithm was used for optimal release of water in reservoir operations. Using the runner, the plant propagates to a new location. The plant searches for a good source of location for its survival. The length of each runner was calculated as dx^i and was used for finding the extent to which runner will reach. The location searching was calculated as $y_{i,j}$. The search equation was used to find optimal release of the reservoir as in equation (12).

$$\mathbf{R(t) = D(t)} \left[\frac{\sqrt{S(t-1)^2 + I(t)^2} - \sqrt{S^2_{dead} + I^2_{min}}}{\sqrt{S^2_{max} + I^2_{max}} - \sqrt{S^2_{dead} + I^2_{min}}} \right]^{y_{i,j}} \tag{12}$$

The search equation is also used for optimal release of dry months as in equation (13).

$$\mathbf{R(t) = D(t)} \left[\frac{S(t-1) - S_{dead}}{S_{max} - S_{dead}} \right]^{y_{i,j}} \tag{13}$$

5. Discussion of Results

Table 1 describes the optimal release of water using plant propagation algorithm. It contains Monthly inflow, storage, demand and release of water of each month of a year. It was calculated for the period of February 2009 to December 2013. The water is released based on available water and demand of a particular month. The demand values represent the water needed for various outflow purposes of particular month of the reservoir. The water that is released should best satisfy the demand range. The months that are not specified with any value in table 1 comes under dry month category where inflow of those months is less than 70% and it is mentioned in table 2. Rule curve is a diagrammatic representation of results of optimal water release for normal months. Rule curves were generated based on Storage, Inflow and Demand as inputs and Release as output for each month. The points on the rule curve indicate the release ranges of all months of a year based on storage, inflow and demand as mentioned in tables. Rule curves are represented in the figures 1 to 5.

Table 1: Optimal Release of dry months from Thirumurthi Reservoir

	2009				2010				2011				2012				2013			
Months*	**I m³**	**S m³**	**D m³**	**R m³**	**I m³**	**S m³**	**D m³**	**R m³**	**I m³**	**S m³**	**D m³**	**R m³**	**I m³**	**S m³**	**D m³**	**R m³**	**I m³**	**S m³**	**D m³**	**R m³**
Jan	-	-	-	-	46	29	22	22	45	29	30	30	40	46	17	17	37	38	43	43
Feb	54	46	31	30	33	44	16	16	46	36	41	40	36	38	38	38	28	32	50	50
Mar	58	39	27	26	54	36	38	34	-	-	-	-	29	31	44	41	-	-	-	-
Apr	43	32	20	19	50	18	45	44	-	-	-	-	-	-	-	-	-	-	-	-
May	-	-	-	-	49	25	41	41	-	-	-	-	-	-	-	-	-	-	-	-
Jun	-	-	-	-	42	25	20	20	-	-	-	-	-	-	-	-	-	-	-	-
Jul	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Aug	49	16	18	18	37	16	48	44	17	27	28	-	-	-	-	-	44	6	40	39
Sept	53	35	38	38	42	35	50	50	43	29	28	53	14	19	18	53	60	20	30	29
Oct	55	38	22	21	50	38	43	42	47	38	39	54	36	27	24	54	60	28	40	38
Nov	23	25	18	17	49	25	13	13	60	28	44	52	36	29	28	52	58	25	8	7
Dec	58	34	10	10	51	34	44	43	51	37	38	52	36	9	9	52	59	28	15	14

I-Inflow, S-Storage, D-Demand, R-Release (measured in million cubic meter m^3)

From the results it is interpreted that in normal months, about 90% to 100% of demand were satisfied. When the storage and inflow were high and demand was less, 99% of demand can be released from the reservoir. When there was deficit in storage and inflow for high demand, release got reduced and during this time about 90% of water can be released. This research has proven that more than 90% of the total demand could be fulfilled during normal months in Thirumurthi Reservoir.

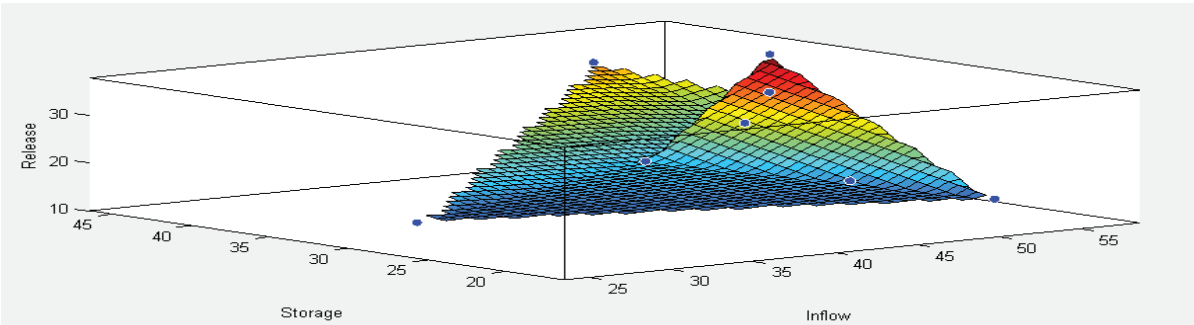

Figure 1: Rule curve-Normal months (2009)

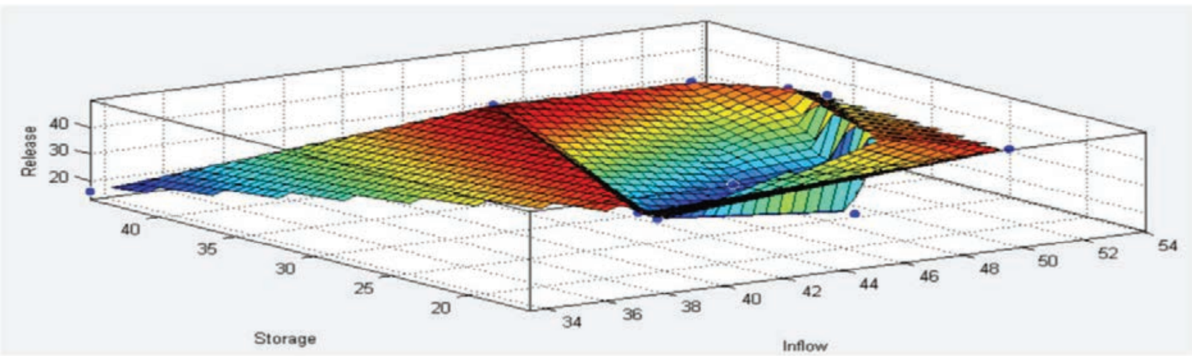

Figure 2: Rule curve-Normal months (2010)

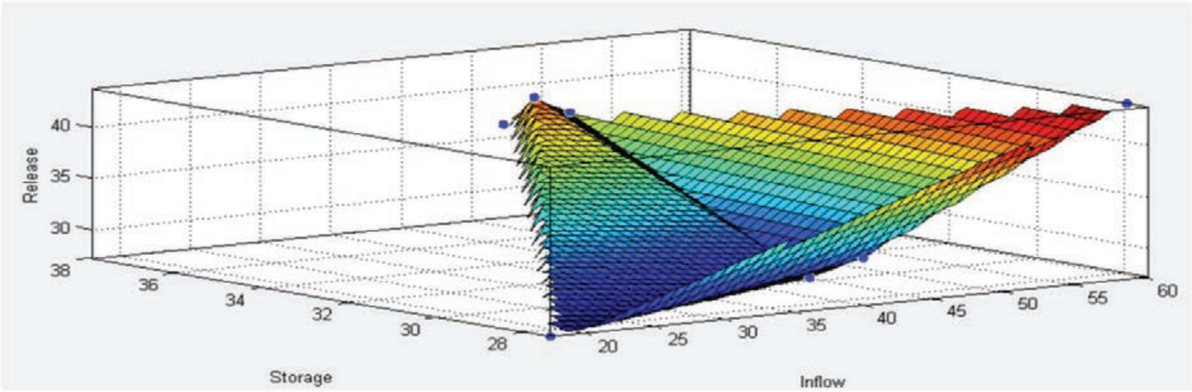

Figure 3: Rule curve-Normal months (2011)

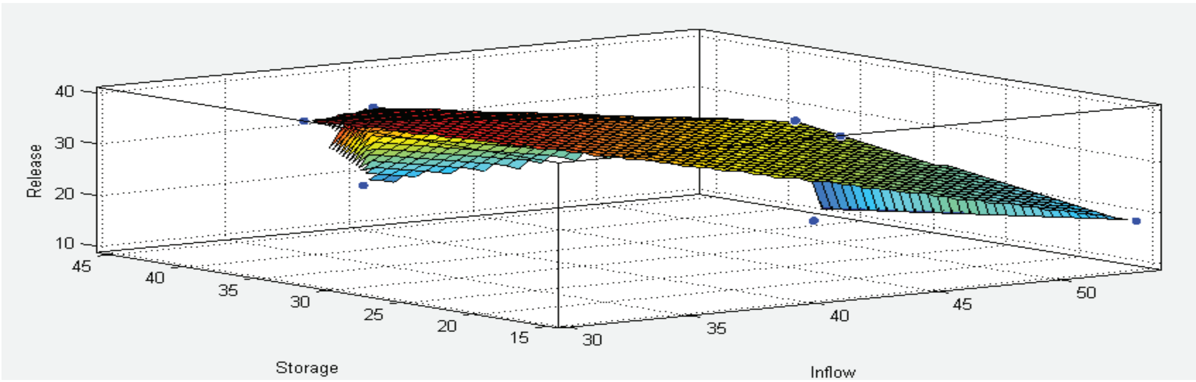

Figure 4: Rule curve-Normal months (2012)

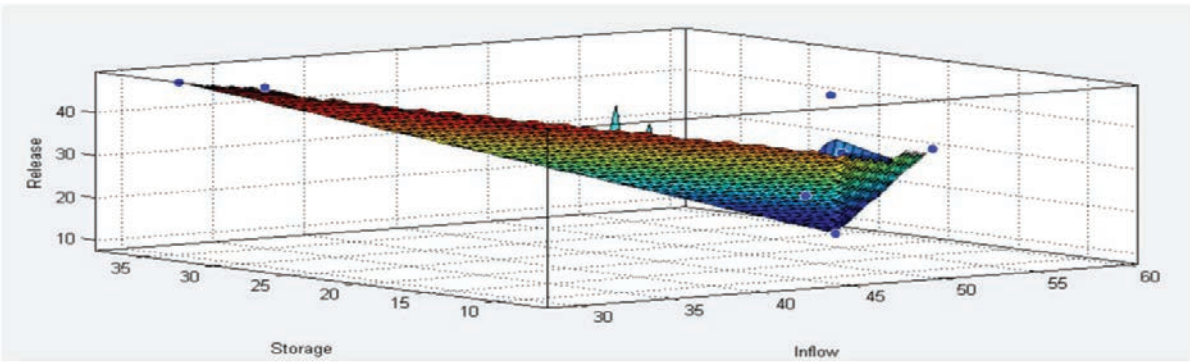

Figure 5: Rule curve-Normal months (2013)

Figures 1 to 5 describe the rule curve for the release of water from the reservoir. Inflow and storage values were taken as input and optimal release values were taken as output in the rule curve. The blue dots on the figure represent the optimal release of water from the reservoir for each month in the table.

The regression based release was also applied to the months having less than 70% inflow, which were considered as dry months. For such months release was calculated only based on the storage. If the available water was greater than the demand, the demand range of water will be released fully and if the available water was less than the demand, the water is optimally released based on available water. If there was no storage of water in reservoir, no water will be released. The parameter is considered that best fits the optimal release of water.

Table 2: Optimal Release of dry months from Thirumurthi Reservoir

Months*	2009			2010			2011			2012			2013		
	S (m^3)	D (m^3)	R (m^3)	S (m^3)	D (m^3)	R (m^3)	S (m^3)	D (m^3)	R (m^3)	S (m^3)	D (m^3)	R (m^3)	S (m^3)	D (m^3)	R (m^3)
Mar	-	-	-	-	-	-	26.08	8	7.34	-	-	-	14.28	39	8.29
Apr	-	-	-	-	-	-	40.16	34	33.83	19.92	11	6.94	11.77	34	9.36
May	27.54	10	9.89	-	-	-	36.68	41	27.65	19.91	39	15.52	10.20	9	6.64
Jun	18.24	27	15.21	-	-	-	32.8	16	15.74	18.24	28	11.01	8.77	14	8.53
Jul	16.78	22	14.42	21.36	17	12.18	28.83	21	9.41	16.36	27	8.63	7.56	20	6.55

S-Storage, D-Demand, R-Release

From the results it is interpreted that about 50% of water and above of demand were satisfied in the dry months. When the storage was above 90% of demand, about 75% to 85% of demand range of water can be released from the reservoir.

Table 3: Comparison of Actual and Optimal Release of water using Plant Propagation Algorithm

Months	2009		2010		2011		2012		2013	
	Optimal (m^3)	Actual (m^3)	Optimal (m^3)	Actual (m^3)	Optimal (m^3)	Actual (m^3)	Optimal (m^3)	Actual (m^3)	Optimal (m^3)	Actual (m^3)
January	-	-	21.97	27.98	29.87	55.30	16.95	51.84	16.95	47.75
February	30.47	62.42	15.99	63.71	39.81	47.27	37.91	37.34	37.91	32.54
March	25.88	61.67	33.9	50.39	7.34	0.43	41.21	30.07	8.29	3.27
April	19.95	55.26	44.79	46.9	33.83	4.33	6.94	1.22	9.36	0.00
May	9.89	4.44	40.96	37.15	27.65	4.15	15.52	0.87	6.64	0.00
June	15.21	0.00	19.9	42.67	15.74	0.0	11.01	0.00	8.53	0.00
July	14.42	0.00	12.18	8.48	9.41	0.0	8.63	0.00	6.55	0.00
August	17.78	19.66	44.39	10.28	27.18	0.0	14.80	0.00	27.30	12.80
September	37.56	67.07	49.99	54.17	27.63	56.67	18.96	43.86	18.96	66.14
October	21.47	66.31	42.68	56.25	36.29	48.82	24.82	40.12	24.82	51.18
November	17.43	1.98	12.98	27.67	43.74	44.89	28.82	60.67	28.82	63.11
December	10	67.46	43.08	53.92	36.92	53.37	8.90	56.06	8.9	54.16

(-) indicates that release pattern is not calculated for that particular month of that particular year.

Table 3 shows the comparison of Actual and Optimal release of water of the Thirumurthi reservoir. It was calculated from February 2009 to December 2013. The optimal releases calculated were compared with actual release of water from the reservoir. Optimal values are the result obtained and Actual values are the release of water from the reservoir which is the data collected from the reservoir.

In the above table we could see values as zero for few months in actual values which means there was no release from the reservoir, whereas for the same month there was a release in optimal values which means, by implementing plant propagation algorithm to reservoir release, we could release little amount of water even in dry months. This was accomplished by optimally releasing water for all the months. From the above table we can predict that the optimal reservoir release was done based on available water and the demand whereas the actual reservoir release was not done with any constraints. There was no uniformity in releasing of water in actual release.

This research work on Reservoir Operations will be useful in releasing water optimally for different patterns of inflow and demands. At present, no reservoirs in Tamilnadu are maintaining demand for outflow of water. No pattern of release was also maintained. The water is released based on availability of water in reservoir. In dry months when there was zero inflow for most of the months, no water was released from reservoirs. In order to overcome these problems, research on optimal reservoir operations for release of water was done using Plant Propagation (Strawberry) algorithm.

6. Summary

In this research work, Through Implicit Stochastic Optimization based strawberry algorithm, release patterns were discovered and rule curve was generated for each release pattern. Various demands were randomly generated for assessing the optimal release of water, which will be useful for systematic maintenance of the reservoir operations by the PWD of the reservoir. Our research has identified the possibility for release of water even in dry months with only stored water where there will be absolutely no inflow to the reservoir.

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